

CLAIMS:

1. A seismic data method for recording and processing vibratory source seismic data, the method comprising
applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal including a reference sweep signal and non-linear noise, said reference signal having a temporal duration,
recording with first recording apparatus said groundforce signal,
generating a filter for converting a time derivative of said groundforce signal to a short-duration wavelet,
recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal, and
applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth.
2. The seismic data method of claim 1 wherein the short duration wavelet has a temporal duration less than the temporal duration of the reference sweep signal.
3. The seismic data method of claim 1 wherein the vibratory source system contacts soil and the seismic data method further comprising
driving the vibratory source system with sufficient peak force so that creation of non-linear noise in the groundforce signal due to non-linearity of the soil and non-linearity in the vibratory source system is enhanced.
4. A seismic data method of claim 1 wherein the reference sweep signal has a bandwidth and the filter has a bandwidth greater than that of the reference sweep signal.
5. The seismic data method of claim 1 wherein the refined seismic data is an improved compressed seismic reflection trace

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3 representative of the location within the earth.

1 6. The seismic data method of claim 1 wherein

2 the at least one reflection signal is a plurality of
3 reflection signals, each reflecting from a different location
4 within the earth back to the recording apparatus and the
5 method further comprising

6 recording with the recording apparatus the plurality
7 of reflection signals, and

8 applying said filter to each of the plurality of
9 reflection signals.

1 7. The seismic data method of claim 1 wherein

2 the at least one reflection signal is a plurality of
3 reflection signals, each reflecting from a different location
4 within the earth back to the recording apparatus, the
5 recording apparatus including a plurality of spaced-apart
6 recording devices each of which receives and records at least
7 one of the plurality of reflection signals, and the method
8 further comprising

9 recording with the recording apparatus the plurality
10 of reflection signals, and

11 applying said filter to each of the plurality of
12 reflection signals.

1 8. The seismic data method of claim 1 wherein the vibratory
2 source system is at earth surface and the second recording
3 apparatus is at earth surface spaced-apart from the vibratory
4 source system.

1 9. The seismic data system of claim 1 wherein the short-
2 duration wavelet has a bandwidth greater than a bandwidth of the
3 reference sweep signal.

1 10. The seismic data method of claim 1 wherein the short-
2 duration wavelet is produced by a method from the group consisting
3 of autocorrelation of the reference sweep signal and a method
4 including designing a zero or minimum phase wavelet with a
5 prescribed amplitude spectrum.

1 11. The seismic data method of claim 10 wherein the short-
2 duration wavelet is a Klauder wavelet.

1 12. The seismic data method of claim 10 wherein the short-
2 duration wavelet is a minimum phase wavelet.

1 13. The seismic data method of claim 1 wherein the filter is
2 generated by dividing a Fourier transform of the short-duration
3 wavelet by a Fourier transform of a time derivative of the
4 groundforce signal.

1 14. The seismic data method of claim 1 wherein the filter is
2 applied to the at least one reflection signal by a circular
3 convolution method.

1 15. The seismic data method of claim 1 wherein particles at
2 the location within the earth are moved by the groundforce signal,
3 the particles then having a velocity, and the ground force signal
4 reflecting from an earth layer beneath earth surface producing the
5 at least one reflection signal indicative of reflectivity of earth
6 at that earth layer and wherein the second recording apparatus
7 includes transducer apparatus for sensing velocity of soil
8 particles adjacent the second recording apparatus and the soil
9 particles moved by the at least one reflection signal, and the
10 method further comprising

11 translating with computing apparatus the at least
12 one reflection signal into the seismic data to which the
13 filter is applied.

1 16. The seismic data method of claim 1 wherein the
2 groundforce signal is measured directly with a force measuring
3 device at the vibratory source system.

1 17. The seismic data method of claim 1 wherein the vibratory
2 source system includes a reaction mass with an interconnected
3 accelerometer and a baseplate with an interconnected accelerometer
4 and a groundforce signal representation is computed from outputs
5 from the accelerometers.

1 18. The seismic data method of claim 1 wherein the non-linear
2 noise includes harmonic distortion due to non-linearity in the

3 vibratory source system and in contact of the vibratory source
4 system and the soil.

1 19. The seismic data method of claim 1 wherein the first
2 recording apparatus is adjacent the vibratory source system.

1 20. The seismic data method of claim 1 wherein the second
2 recording apparatus is adjacent the vibratory source system.

1 21. The seismic data method of claim 1 wherein the first and
2 second recording apparatus are adjacent the vibratory source
3 system.

1 22. The seismic data method of claim 1 wherein the first and
2 second recording apparatus are remote from the vibratory source
3 system and the method further comprising

4 transmitting with first transmitting apparatus a
5 signal representative of the groundforce signal to the first
6 recording apparatus, and

7 transmitting with second transmitting apparatus a
8 signal representative of the at least one reflection signal to
9 the second recording apparatus.

1 23. The seismic data method of claim 1 wherein a computer is
2 interconnected with the vibratory source system and with the first
3 and second recording apparatus and the computer computes the short-
4 duration wavelet and generates the filter.

5 24. The seismic data method of claim 23 wherein the computer
6 applies the filter to the at least one reflection signal.

1 25. The seismic data method of claim 23 wherein the computer
2 is adjacent the vibratory source system.

1 26. The seismic data method of claim 23 wherein the computer
2 is remote from the vibratory source system.

1 27. The seismic data method of claim 1 wherein the first and
2 second recording apparatus are a single recording apparatus.

1 28. The seismic data method of claim 22 wherein the first and
2 second transmitting apparatus are a single transmitting apparatus
3 in intercommunication with both the vibratory source system and the
4 recording apparatuses.

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1 29. A seismic data method for recording and processing
2 vibratory source seismic data, the method comprising

3 applying with a vibratory source system a
4 groundforce signal into earth at a selected location, said
5 groundforce signal including a reference sweep signal and non-
6 linear noise, said reference signal having a temporal
7 duration,

8 recording with first recording apparatus said
9 groundforce signal,

10 generating a filter for converting a time derivative
11 of said groundforce signal to a short-duration wavelet,

12 recording with second recording apparatus at least
13 one reflection signal from a location within the earth of said
14 groundforce signal,

15 applying said filter to said at least one reflection
16 signal to refine seismic data represented by said at least one
17 reflection signal producing refined seismic data about the
18 location within the earth,

19 wherein $F(\omega)$ is a function of the filter and

20
$$F(\omega) = \frac{W(\omega)}{G_F^*(\omega)}$$

21 where

22 $F(\omega)$ = Fourier transform of the filter

23 $W(\omega)$ = Fourier transform of the wavelet

24 $G_F(\omega)$ = Fourier transform of the groundforce
signal

25 the filter applied to the seismic data, $D(\omega)$, as
26 $F(\omega) \cdot D(\omega)$

27 where

28
$$D(\omega) = G_F^*(\omega) \cdot R_E(\omega) \cdot M_E(\omega)$$

29 where

30 G_F groundforce

31 G_M measured groundforce

32 measured seismic data
 33 R_E earth reflectivity sequence
 34 W desired wavelet
 35 M_E earth filter (e.g. a Q-filter)
 36 and the refined seismic data is T:

$$\frac{W(\omega)}{G_F(\omega)} \cdot G_F(\omega) \cdot R_E(\omega) \cdot M_E(\omega) =$$

$$R_E(\omega) \cdot M_E(\omega) \cdot W(\omega) = D_C(\omega) = T$$

1 30. A method for making a shaping filter for improving
 2 seismic data, the seismic data comprising a reflected signal from
 3 earth, the reflected signal comprising the reflection of a noise-
 4 containing groundforce signal generated by a vibratory source
 5 system, the groundforce signal including a reference sweep signal
 6 and non-linear noise, the reference sweep signal having a temporal
 7 duration, the method comprising

8 producing a short-duration wavelet with a temporal
 9 duration less than that of the reference sweep signal, and

10 generating the filter by dividing a Fourier
 11 transform of the short-duration wavelet by a Fourier transform
 12 of a time derivative of the groundforce signal.

13 31. The method of claim 30 wherein $F(\omega)$ is a function of
 14 the filter and the filter is computed as

$$F(\omega) = \frac{W(\omega)}{i\omega G_F}$$

3 where:

4 $W(\omega)$ = Fourier transform of the desired, short-duration
 5 wavelet

6 $G_F(\omega)$ = Fourier transform of the recorded force signal
 7 output of the vibrator

8 $F(\omega)$ = Fourier transform of the filter

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$$i = \sqrt{-1}; \omega = 2\pi f$$

32. A method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a bandwidth duration, the method comprising

producing a short-duration wavelet with a bandwidth greater than that of the reference sweep signal, and

generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

33. The method of claim 32 wherein $F(\omega)$ is a function of the filter and the filter is computed as

$$F(\omega) = \frac{W(\omega)}{i\omega G_f}$$

where:

$W(\omega)$ = Fourier transform of the desired, short-duration wavelet

$G_f(\omega)$ = Fourier transform of the recorded force signal output of the vibrator

$F(\omega)$ = Fourier transform of the filter

$$i = \sqrt{-1}; \omega = 2\pi f$$

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